

Perfluorohexane sulfonic acid (PFHxS), its salts and PFHxS-related compounds

DRAFT RISK MANAGEMENT EVALUATION

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Table of contents

Executive summary	2
1. Introduction	3
1.1 Chemical identity of PFHxS.....	3
1.2 Conclusions of the POPs Review Committee, Annex E information.....	4
1.3 Data sources	4
1.4 Status of the chemical under international conventions	4
1.5 Any national or regional control action taken	5
2. Summary information relevant to the risk management evaluation.....	6
2.1 Identification of possible control measures	7
2.2 Efficacy and efficiency of possible control measures in meeting risk reduction goals	7
2.2.1 Technical feasibility	8
2.2.2 Cost and benefits of implementing control measures.....	8
2.3 Information on alternatives (products and processes) where relevant.....	8
2.3.1 Application-specific alternative substances.....	8
2.3.1.1 Fire-fighting foam (AFFF)	9
2.3.1.2 Metal plating	11
2.3.1.3 Textiles including leather and upholstery	12
2.3.1.4 Polishing agents and cleaning/washing agents	13
2.3.1.5 Coatings, impregnation/proofing (for protection from damp, fungus, etc.)	13
2.3.1.6 Manufacturing of electronics and semiconductors.	13
2.3.2 Other uses.....	14
2.4 Summary of information on impacts on society of implementing possible control measures	14
2.4.1 Health, including public, environmental and occupational health.....	14
2.4.2 Agriculture, including aquaculture and forestry	15
2.4.4 Economic aspects and social costs	16
2.4.5 Movement towards sustainable development.....	17
2.5 Other considerations.....	17
2.5.1 Access to information and public education.....	17
2.5.2 Status of control and monitoring capacity	18
3. Synthesis of information	18
3.1 Summary of risk profile information.....	18
3.2 Summary of risk management evaluation information	19
3.3 Suggested risk management measures	20
4. Concluding statement.....	20
References	21

Executive summary

1. In May 2017, Norway submitted a proposal to list perfluorohexane sulfonic acid (PFHxS), its salts and PFHxS-related compounds in Annexes A, B and/or C to the Stockholm Convention. The proposal (UNEP/POPS/POPRC.13/4) was reviewed and adopted (decision POPRC-13/3) by the Persistent Organic Pollutants Review Committee (POPRC) at its thirteenth meeting in October 2017. The Committee decided to establish an intersessional working group to prepare a draft risk profile for PFHxS, its salts and PFHxS-related compounds for consideration at its fourteenth meeting in October 2018. The Committee adopted the risk profile (UNEP/POPS/POPRC.14/6/Add.1) and established an intersessional working group to prepare a risk management evaluation that includes an analysis of possible control measures for PFHxS in accordance with Annex F to the Convention for consideration at its fifteenth meeting.
2. The substances covered in this risk management evaluation include PFHxS (CAS No: 355-46-4), its salts and PFHxS-related compounds, defined as any substances that contain the chemical moiety C₆F₁₃SO₂ as one of their structural elements and that potentially degrade to PFHxS.
3. Historical production was mainly carried out by 3M, which phased out its production of C₆, C₈ and C₁₀ perfluoroalkyl sulfonic acids (PFASs) in 2002. Information about current global manufacture of PFHxS, its salts and PFHxS-related compounds are limited. A few producers located in China have been identified, however quantitative production data are not publicly available. PFHxS, its salts and many PFHxS-related compounds have been listed on national chemical inventories (Australia, China, Canada, EU, Japan, Nordic countries and US) indicating historical/present production, import and/or uses of products containing these substances.
4. PFHxS, its salts and PFHxS-related compounds have been intentionally used at least in the following applications: (1) Aqueous Film-Foaming Foams (AFFFs) for firefighting; (2) metal plating; (3) textiles, leather and upholstery; (4) polishing agents and cleaning/washing agents; (5) coatings, impregnation/proofing (for protection from damp, fungus, etc.); and (6) within the manufacturing of electronics and semiconductors. Other potential use categories may include pesticides, flame retardants, paper, and oil industry. In addition, PFHxS, its salts and PFHxS-related compounds have been used in certain per- and polyfluoroalkyl substances (PFASs) based consumer products. PFHxS are and have been unintentionally produced during the electrochemical fluorination (ECF) processes of some other PFASs. In many applications, PFHxS has been used as a replacement for perfluorooctane sulfonic acid (PFOS). For all potential use categories alternatives are available.
5. The limited information available on intentional use of PFHxS and PFHxS-related compounds indicate that these are similar to PFOS. Assessment of alternatives to PFOS, its salts and perfluorooctane sulfonyl fluoride (PFOSF) indicate that technically feasible alternatives are available for all applications. Furthermore, no request for exemptions due to critical use of PFHxS, its salts or PFHxS-related compounds has been requested suggesting the switch to chemical alternatives and non-chemical technical solutions are feasible.
6. The activities of the Strategic Approach to International Chemicals Management (SAICM) at the global level focus on gathering and exchanging information on perfluorinated chemicals and to support the transition to safer alternatives. Voluntary efforts to phase out long chain PFAS and related substances (including PFHxS) have been implemented, such as by the United States Environment Protection Agency (USEPA). In 2017, PFHxS, its salts and PFHxS-related compounds were identified in the EU as Substances of Very High Concern (SVHC) and added to the EU Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) Candidate List due to their persistent and bioaccumulative properties.
7. PFHxS is ubiquitous in environmental compartments such as surface water, deep-sea water, drinking water, waste-water treatment plants, leachates from landfills, sediment, groundwater, soil, the atmosphere, dust, as well as biota (including wildlife), and humans globally. Emissions of PFHxS to the environment occur at all its life cycle stages but are assumed to be highest during service life and in the waste phase. Global emission inventory estimates indicate that environmental concentrations of the raw material perfluorohexane sulfonyl fluoride (PHxSF) and its derivatives are expected to continue for decades, and that areas far from the source regions have not yet reached their estimated peak concentrations. Efficient control measures for the handling of waste will be essential to reduce environmental levels. According to Article 6 of the Convention, waste shall be disposed of in such a way that the POP content is destroyed or irreversibly transformed so that it does not exhibit the characteristics of POPs, or otherwise disposed of in an environmentally sound manner when destruction or irreversible transformation does not represent the environmentally preferable option, or the POP content is low.
8. Based on information such as price, accessibility and availability of alternatives as well as information on regulatory measures and use in different countries, the socioeconomic costs of implementing a ban and/or restriction on the use of PFHxS are considered small and outweighed by the benefits of elimination/regulation. High costs are estimated for remediation of old and current fire-fighting foam training sites and airports, landfills for industrial waste and hazardous waste, as well as for removal of PFASs, including PFHxS, from drinking water and water sources in the vicinity of these sites.

9. A positive impact on human health and the environment can be expected from a global elimination or reduction of PFHxS, its salts and PFHxS-related compounds. Therefore, the most effective control measure would be to list the substances in Annex A of the Convention with no exemptions for production and use.

1. Introduction

1.1 Chemical identity of PFHxS

10. The chemical identity of PFHxS is described in the risk profile (UNEP/POPS/POPRC.14/6/Add.1) and is in line with the decision taken at the thirteenth meeting of the POPs Review Committee (POPRC-13/3). The chemical identity includes:

- (a) Perfluorohexane sulfonic acid (CAS No: 355-46-4, PFHxS);
- (b) Any substance that contains the chemical moiety $C_6F_{13}SO_2^-$ as one of its structural elements and that potentially degrades to PFHxS.

11. A number of chemicals are included in the group of PFHxS, its salts and PFHxS-related compounds including isomers. OECD has developed a new list of per and poly-fluorinated chemicals containing as many as 4730 substances and this list contains PFHxS-related/precursor/polymer substances including PFHxS (CAS No: 355-46-4) (<http://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/>). Furthermore, the restriction proposal developed under REACH contains 147 PFHxS compounds (reference will be provided at a later point). This non-exhaustive list of 147 compounds was provided with the letter requesting Annex F information sent to Parties and observers by the Secretariat in 2018. This list of PFHxS, its salts and PFHxS-related compounds, as well as polymers and mixtures, was compiled from the database of PFAS substances identified by the OECD and Appendix II (Non-exhaustive lists of perfluorohexane sulfonic acid and its related substances identified in Norwegian Environment Agency report M-792) of the annex to document UNEP/POPS/POPRC.14/INF/4.

12. Table 1 below lists the chemical identity of PFHxS and Table 2 lists selected modelled and experimental physico-chemical properties for PFHxS.

Table 1. Chemical identity of PFHxS

CAS number:	355-46-4
IUPAC name:	1,1,2,2,3,3,4,4,5,5,6,6,6-tridecafluorohexane-1-sulfonic acid
EC number:	206-587-1
EC name:	Perfluorohexane-1-sulfonic acid
Molecular formula:	$C_6F_{13}SO_3H$
Molecular weight:	400.11
Synonyms:	PFHxS PFHS Perfluorohexanesulfonic acid; 1,1,2,2,3,3,4,4,5,5,6,6,6-Tridecafluorohexane-1-sulfonic acid; Tridecafluorohexane-1-sulfonic acid; 1-Hexanesulfonic acid, 1,1,2,2,3,3,4,4,5,5,6,6,6-tridecafluoro-; 1,1,2,2,3,3,4,4,5,5,6,6,6-Tridecafluoro-1-hexanesulfonic acid; Tridecafluorohexanesulfonic acid
Trade names	RM70 (CAS No: 423-50-7), RM75 (3871-99-6), and RM570 (CAS No: 41997-13-1) (PFHxS-related substances produced by *Miteni SpA, Italy). FC-95 Fluorad brand fluorochemical surfactant (CAS No: 3871-99-6). Contains PFHxS-K produced by 3M.

*Miteni filed bankruptcy in November 2018.

Table 2. Overview of relevant physicochemical properties of PFHxS

Property	Value	Reference
Physical state at 20°C and 101.3 kPa	Solid white powder for PFHxSK	As referenced in ECHA, 2017a (Company provided)
Melting point	320 K (41°C)	Kim et al., 2015
Boiling point	238–239°C	Kosswig, 2000 (measured)

Property	Value	Reference
pK _a	-3.45 -3.3±0.5 -5.8±1.3	Wang et al., 2011 (COSMOtherm) ACD/Percepta 14.2.0 (Classic) ACD/Percepta 14.2.0 (GALAS)
Vapour pressure	58.9 Pa (0.0046 mmHg)	Wang et al., 2011(COSMOtherm)*
Water solubility	1.4 g/L (PFHxSK; 20–25°C) 2.3 g/L (non-dissociated)	Campbell et al., 2009 (measured) Wang et al., 2011 (COSMOtherm)*
Air/water partition coefficient, K _{aw} (log value)	-2.38	Wang et al., 2011 (COSMOtherm)*
n-Octanol/water partition coefficient, K _{ow} (log value)	5.17	Wang et al., 2011 (COSMOtherm)*
Octanol-air partition coefficient K _{oa} (log value)	7.55	Wang et al., 2011 (COSMOtherm)*
Organic carbon/water partition coefficient K _{oc} (log value) (mobility)	2.05 2.40 2.31 (range 1.8–2.76)	Guelfo and Higgins, 2013 (measured) D'Augustino & Mabury, 2017 (measured) Chen et al., 2018 field-based

1.2 Conclusions of the POPs Review Committee, Annex E information

13. In May 2017, Norway submitted a proposal to list perfluorohexane sulfonic acid (PFHxS), its salts and PFHxS-related compounds in Annexes A, B and/or C to the Convention. At its thirteenth meeting, the Committee reviewed the proposal (UNEP/POPS/POPRC.13/4) and decided to establish an intersessional working group to prepare a draft risk profile for PFHxS, its salts and PFHxS-related compounds (decision POPRC-13/3). At its fourteenth meeting, the Committee adopted the risk profile (UNEP/POPS/POPRC.14/6/Add.1) was adopted and decided that PFHxS, its salts and PFHxS-related compounds are likely as a result of their long-range environmental transport to lead to significant adverse human health and environmental effects such that global action is warranted (decision POPRC-14/1). The Committee established an intersessional working group to prepare a risk management evaluation that includes an analysis of possible control measures for PFHxS in accordance with Annex F to the Convention for consideration at its fifteenth meeting.

1.3 Data sources

14. The risk management evaluation was developed using information contained in the risk profile (UNEP/POPS/POPRC.14/6/Add.1) and Annex F information submitted by Parties and observers. Information was submitted by the following Parties and observers: Canada, Germany, Sweden, India, Japan, United Kingdom (UK), South Korea (waiting for submission) and Denmark (waiting for submission), Imaging and Printing Association Europe (I&P Europe), and the International POPs Elimination Network (IPEN). All submissions of Annex F information are available on the Convention website.¹

15. Scientific literature obtained from scientific databases such as ISI Web of Science and PubMed was included as well as other publicly available information such as government reports, risk- and hazard assessments, industry fact sheets etc.

1.4 Status of the chemical under international conventions

16. Perfluorinated chemicals were identified under the Strategic Approach to International Chemicals Management (SAICM) as an issue of concern. Efforts are focused on gathering and exchanging information on perfluorinated chemicals and to support the transition to safer alternatives (<http://www.saicm.org/tabid/5478/Default.aspx>). OECD provided a recent overview on risk reduction approaches for PFASs across countries (OECD, 2015). Responses from participating countries indicated that risk reduction approaches for PFASs are mainly covered under existing national and/or regional regulatory frameworks and cover principally long chain PFASs and their precursors and salts. The type of risk reduction approaches implemented across countries varies, but there is often a combination of voluntary and regulatory approaches that are used.

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<http://chm.pops.int/TheConvention/POPsReviewCommittee/Meetings/POPRC14/POPRC14Followup/PFHxSInfoSubmission/tabid/7826/Default.aspx>.

1.5 Any national or regional control action taken

17. In 2017, PFHxS and its salts were identified as Substances of Very High Concern (SVHC) and added to the EU REACH Candidate List due to their persistent and bioaccumulative properties (ECHA, 2017a). Toxicity and ecotoxicity have not been evaluated in the SVHC evaluation process. Inclusion on this list means that the substances can be subject to an authorization procedure under which the substances can only be used for specific authorized purposes under strictly controlled conditions. Such listing initiates the duty of suppliers to communicate information on PFHxS above a concentration of 0.1% in articles according to Article 33 of REACH (Germany Annex F information). As a follow-up, Norway has prepared a proposal to amend REACH Annex XVII to restrict the manufacture, use and placing on the market of perfluorohexane-1-sulphonic acid, its salts and related substances, with a planned dossier submission date of 12 April 2019 (reference will be added when available).

18. Some PFHxS-related substances are listed on the Canadian Domestic Substances List (DSL) (Environment Canada, 2013), an inventory of substances manufactured in, imported into or used in Canada on a commercial scale. Any person who intends to import or manufacture a substance in Canada that is not listed on the DSL (such as PFHxS or PHxSF) must submit a notification required under the New Substances Notification Regulations. These regulations ensure that new substances are not introduced into the Canadian marketplace before undergoing ecological and human health assessments. Management measures may be imposed under this process to mitigate any risks to the environment or human health. In the United States new uses of the chemicals in this group are prohibited without prior approval from the United States Environmental Protection Agency (USEPA) (United States Government, 2002; 2007). The USEPA published an action plan on long-chain PFASs, including PFHxS, and their salts and precursors in 2009. All chemicals were identified as persistent, bioaccumulative and toxic (USEPA, 2009). The state of Washington has recently adopted a bill banning the use of perfluorinated chemicals in food packaging (<https://www.foodpackagingforum.org/news/washington-state-bans-pfass-in-food-packaging>). In Australia, NICNAS has developed an action plan for assessment and management of chemicals which may degrade to PFCAs, PFSA, and similar chemicals. The primary assumption outlined in this action plan is that chemicals with a perfluorinated chain terminated by a sulfonyl group will degrade to the perfluoroalkyl sulfonate (of the same chain length) (NICNAS 2017, a, b, c or d). In Norway, PFHxS, its salts and PFHxS-related compounds was recently added to the national list of priority substances (Prioritetslista <http://www.miljostatus.no/prioritetslisten>) with a national goal to phase out the use by 2020.

19. No harmonized classification or labelling is available for PFHxS either in the EU or globally. However, in Australia PFHxS-related compounds are included in the Inventory Multi-Tiered Assessment and Prioritisation (IMAP) framework, which includes both human health and environmental assessments (NICNAS 2017c). Based on the NICNAS action plan to assess and manage chemicals which may degrade to perfluorinated carboxylic acids, perfluoroalkyl sulfonates and similar chemicals, where chemical specific data was not available, the perfluorooctane sulfonate (PFOS) hazard information was used to estimate the systemic health hazard of potassium PFHxS, ammonium PFHxS, diethanolammonium PFHxS and perfluorohexane sulfonyl fluoride (PHxSF). In relation to human health risks, potassium PFHxS, ammonium PFHxS, diethanolammonium PFHxS and PHxSF were identified as: toxic if swallowed - Cat. 3 (H301), causes serious eye irritation - Cat. 2A (H319), causes damage to organs through prolonged or repeated exposure if swallowed - Cat. 1 (H372), suspected of causing cancer - Cat. 2 (H351) using the UN Globally Harmonized System of Classification and Labelling of Chemicals (GHS). In EU, self-classifications have been submitted by industry with the notification to the C&L inventory under the EU legislation, for PFHxS and several PFHxS-related substances for acute Tox. 4 and Skin Corr. 1B, STOT SE 3 (inhalation, lung), Skin Irrit. 2, Eye Irrit. 2 (<https://www.echa.europa.eu/en/information-on-chemicals/cl-inventory-database>).

20. Information concerning PFASs including PFHxS will have to be reported to the Products Register at the Swedish Chemicals Agency for the first time in February 2020. This applies regardless of the concentration of the substances, although the concentration itself doesn't need be specified (Kemi, 2018).

21. In 2014, the Danish EPA published a study on groundwater contamination associated with point sources of perfluoroalkyl substances, including PFHxS and PFHxS-related compounds. Based on the findings of groundwater contamination, a study assessing and proposing health-based quality criteria was commissioned. This study led to establishing a sum criterion drinking water limit value for 12 PFASs (PFBS, PFHxS, PFOS, PFOSA, 6:2 FTS, PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA and PFDA). The limit value is 0.1 µg/L drinking water and is a sum criterion for the presence of all the 12 PFASs (Denmark, 2018). The same sum criterion limit value is valid for groundwater. The Swedish National Food Agency has recommended limits of 0.09 µg/L, for drinking water based on the presence of sum of 11 PFASs (PFBS, PFHxS, PFOS, 6:2 FTSA, PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA and PFDA) (Sweden, 2018). In the proposal for a new European Drinking Water Directive, which is under discussion, a limit value is proposed for the group of PFASs. Values of 0.1 µg/L for each individual PFAS and 0.5 µg/L for PFASs in total has been suggested (Europe 2018).

22. The USEPA issued a lifetime drinking water health advisory for PFOS and PFOA of 0.07 µg/L (USEPA, 2016). In Australia, health-based drinking water guidance values are set at 0.07 µg/L for the sum of PFOS and PFHxS

and 0.7 µg/L for recreational waters (Australian Government, 2017), and these values have also been adopted in New Zealand (<http://www.mfe.govt.nz/node/24415>).

23. The Danish government recommend not to use PFAS and organic fluoro-compounds in paper and has issued an advisory limit for PFASs in food packaging materials of 0.35 µg/decimeter² paper of organic fluorine (Denmark, 2015).

2. Summary information relevant to the risk management evaluation

24. As described in the risk profile, PFHxS, its salts and PFHxS-related compounds have been intentionally used at least in the following applications: (1) AFFFs for firefighting; (2) metal plating; (3) textiles, leather and upholstery; (4) polishing agents and cleaning/washing agents; (5) coatings, impregnation/proofing (for protection from damp, fungus, etc.); and (6) within the manufacturing of electronics and semiconductors. In addition, other potential use categories may include pesticides, flame retardants, paper, and in the oil industry. Furthermore, there are indications that PFHxS is used to wash semiconductors, to coat frying pans and to kill pests in South Korea (<http://koreajoongangdaily.joins.com/news/article/article.aspx?aid=3049751>). Annex F information submitted by the UK reported that a waste company responded to the request for information that the substance is used in textiles, carpet protectors, leather, papermaking, pesticides, electroplating, firefighting foams, photosensitive material and some synthetic materials. It has also been found in printing inks, sealants and in non-stick cookware. Although according to the information in the UK Annex F information, no use or production of the chemical as a raw product takes place, it is assumed that there will be some embedded in everyday materials (UK Annex F information).

25. Details on these identified uses and the available alternatives are elaborated in section 2.3.

26. Furthermore, it should be noted that information on the volumes and uses of PFHxS, its salts and PFHxS-related compounds has been reported to the competent authorities in Denmark, Sweden and Norway, but most of such information has been claimed as confidential business information (SPIN, 2018; Norwegian Environment Agency M-961/2018). A recent source analysis showed that PFHxS was associated with hydraulic fluid formulations, AFFF factories, metal plating, manufacturing and processing of fluoropolymer and food contact material in coastal areas of Bohai Bay, China (Liu et al., 2019). In addition, PFHxS has been detected in several consumer products such as various forms of textile including upholstery, carpets, electrical items and building material (Becanova et al., 2016).

27. The raw material used for manufacture of PFHxS, its salt and PFHxS-related compounds, PHxSF (CAS No: 423-50-2), is available from several providers (https://www.lookchem.com/product_High-quality-Perfluorohexane-Sulphonyl-Fluoride/14315526.html) and is advertised for the following uses; "this product is one of the most essential raw materials for preparing fluorine-containing surfactants. The fluorine-containing surfactant can be widely used in textile, leather, papermaking, pesticide, electroplating, oilfield, fire control, photosensitive material, synthetic material and other fields". Furthermore, a total of six manufacturers are established in China (<https://www.lookchem.com/newsell/search.aspx?key=423-50-7&countryId=1&businessType=Manufacturers>) showing evidence for production of PHxSF. Furthermore, a number of manufacturers and/or suppliers of PFHxS (CAS No: 355-46-4) are registered on the following web page (<https://www.lookchem.com/newsell/search.aspx?p=1&key=355-46-4&ad=>) suggesting significant use and availability.

28. To date, limited research has been conducted to specifically study the releases of PFHxS, its salts and PFHxS-related compounds in the environment, resulting in a lack of quantitative information on releases, although various studies have detected the ubiquitous presence of PFHxS in the environment (see risk profile UNEP/POPS/POPRC.14/6/Add.1). The occurrence of PFHxS and its related compounds in the environment is a result of anthropogenic production, use and disposal, since they are not naturally occurring substances.

29. High concentrations of PFHxS have been detected in several Chinese PFOS substitute products. These products are mainly used in surfactants for AFFF, e.g. VF-230 (5,082 mg/L), VF-9126 (1771 mg/L), and VF-9128 (583 mg/L). According to the producer of the above mentioned AFFF products, the alternative "non-PFOS" fluorocarbon surfactants were purchased from the vendors with the guarantee of being non-PFOS substitutes. However, the content of PFHxS was not provided for the non-PFOS alternative (https://www.switchmed.eu/en/documents/huang_pfos-substitution-in-china.pdf).

30. Historically, 3M was likely the biggest global manufacturer of PFHxS, its salts and PFHxS-related compounds, with an annual production of about 227 tonnes of PHxSF in the US in 1997 (3M, 2000a). In 2000 – 2002, 3M ceased its production of PFHxS, its salts and PFHxS-related compounds (3M, 2000a). Recently, some manufacturers in China and Italy have reportedly produced PFHxS and its precursors (reviewed in Boucher et al., 2019) potentially as a replacement for PFOS and its precursors (Löfstedt et al., 2016). The information on production in China correspond well with environmental data, such as high levels of PFHxS in lakes and rivers in Asia (Ma et al., 2018; Pan et al., 2018; Cui et al., 2018). For example, in a study by Ma et al., (2018) PFHxS was the predominant PFAS compound in Taihu Lake and flow-in river waters. Levels of PFHxS (45.9–351 ng/L) exceeded PFOS levels in Taihu Lake and this increase of PFHxS was linked to production and use of PFHxS as an alternative due to recent

regulation of PFOS (Ma et al., 2018). The flux of total PFASs to the Lake was 1255 kg/year and was mainly contributed by PFHxS (611 kg/year), PFOS (227 kg/year), PFOA (182 kg/year), and PFHxA (84.4 kg/year). A recent paper reported increased concentrations in rivers in China. The estimated load of PFHxS to these rivers were 21.6 tonnes in 2016, up from 0.09 tonnes in 2013 (Pan et al., 2018).

31. A global emission inventory of C₄–C₁₀ perfluoroalkanesulfonic acids (PFASs) and related precursors was recently published (Boucher et al., 2019). It reviews and integrates existing information on the life cycle of the raw material PHxSF and its derivatives. Using the same methodology to develop and validate an emission inventory as was used for an earlier study on POSF (Wang et al., 2017) an inventory for PHxSF was developed and used as inputs for the global mass-balance environmental fate model, CliMoChem, to estimate environmental concentrations, which were then compared to field measurements. The estimated emission inventories included the range of global total emissions from the life cycle for PHxSF-based products. The global emission from individual source categories for different time periods are reported. In the time-period 2016 – 2030, it is estimated a total global emission of 2 – 89 tonnes of PFHxS from production, use and disposal, degradation of PFHxS-related compounds and from degradation of PHxSF. Highest emissions of PFHxS over this period were estimates from use and disposal (1-21 tonnes), and from degradation of PFHxS-related compounds (1-66 tonnes) (Boucher et al., 2019). The results show that elevated environmental concentrations of PHxSF and its derivatives are expected to continue for decades, and that areas far from the source regions have not yet reached their estimated peak concentrations. These estimated trends are likely to be widely representative on a large geographical scale; however, the currently nonquantifiable emissions of intentional production of PHxSF-based products in China (and possible other countries) may increase levels of local exposure in some areas and are not captured by the current study (Boucher et al., 2019).

2.1 Identification of possible control measures

32. PFHxS is likely as a result of its long range environmental transport to lead to significant adverse human health and environmental effects such that global action is warranted (UNEP/POPS/POPRC.14/16/Add.1). Furthermore, no need for exemptions in any application has been requested by any party during the preparation of this document. This suggests that a complete phase-out of PFHxS from all uses is possible and that exemptions for production and use are not necessary. The most effective control measure would be to list PFHxS in Annex A to the Convention with no exemptions for production and use.

33. PFHxS, its salts and PFHxS-related compounds may therefore be listed in Annex A, without specific exemptions.

34. The alternative option would be to list PFHxS in Annex A with specific exemptions or in Annex B with specific exemptions and acceptable purposes. However, no critical uses have been identified for PFHxS and PFHxS-related compounds and according to the Annex F information submitted by Parties and observers, technically feasible alternatives appear to be available for all applications.

35. The control measures for PFHxS, its salt and PFHxS-related compounds for its prohibition of production, use, import and export may be achieved in different ways under the Convention and may include (1) prohibition or restriction of production, use, import and export, (2) control of discharges or emissions, (3) replacement of the chemicals by alternatives, (4) clean-up of contaminated sites, (5) environmentally sound management of obsolete stockpiles, (6) prohibition of reuse and recycling of wastes or stockpiles.

36. Following a listing of PFHxS, its salts and PFHxS-related compounds in the Convention, the provisions of Article 6(1)(d)(ii) must be fulfilled. This means that waste shall be disposed of in such a way that the POP content is destroyed or irreversibly transformed so that it does not exhibit the characteristics of POPs, or otherwise disposed of in an environmentally sound manner when destruction or irreversible transformation does not represent the environmentally preferable option, or the POP content is low. Parties should also consider emission reduction measures and the use of best available techniques and best environmental practices (BAT/BEP) in the waste management phase. In addition, Parties shall endeavour to develop appropriate strategies for identifying sites contaminated with PFHxS. If contaminated sites are identified and remediation is undertaken, it shall be performed in an environmentally sound manner.

2.2 Efficacy and efficiency of possible control measures in meeting risk reduction goals

37. To reduce PFHxS emissions, control measures at all life cycle stages need to be in place. Hence, the most cost-effective and practicable control measure for PFHxS, its salts and related compounds is the prohibition of all production, use, import and export. This will be best accomplished by listing PFHxS, its salts and PFHxS-related compound in Annex A to the Stockholm Convention with no exemptions. Measures under Article 6 would address environmentally sound management of stockpiles and wastes and clean-up of contaminated sites (if undertaken) such as at or near manufacturing facilities, airports, military bases and other sources.

38. Furthermore, no requests for exemptions have been raised and no critical uses have been identified. Therefore, it should be possible to discontinue all production and use within a short period of time and consequently stop

emission and releases from manufacturing facilities and from facilities that use PFHxS, its salts and PFHxS-related compounds in their products (such as textile and leather treatment, semiconductor manufacture etc).

39. The USEPA uses a combination of regulatory and voluntary approaches, including Significant New Use Rules and the voluntary Stewardship Program (OECD, 2015). The USEPA has established health advisory levels for PFOA and PFOS in drinking water at 70 ppt, and when both PFOA and PFOS are found in drinking water the combined concentrations of PFOA and PFOS will be 70 ppt as well (<https://www.govinfo.gov/content/pkg/FR-2016-05-25/pdf/2016-12361.pdf>). In the US, several States have set their own health advisory limits for PFASs in drinking water, and updated information of levels of PFASs in ground and surface water are publicly available (<https://www.ewg.org>). In Russia, several short- and middle-chain PFASs are regulated in occupational air and water and are generally referred to as low hazardous substances (OECD, 2013). Australia has also identified 18 high-priority defence sites where groundwater is contaminated with PFAS including PFHxS (<http://www.defence.gov.au/Environment/PFAS/Publications/Default.asp>). For PFOS, PFOA and PFHxS, Australia has implemented precautionary health-based guidance values, expressed as a tolerable daily intake (TDI), for use when investigating contaminated sites and conducting human health risk assessments (Australia Gov. 2016)

40. The Swedish Chemicals Agency has published a strategy for reducing the use of PFASs (KEMI, 2016b). PFAS applications which could result in environmental contamination should be minimized and ultimately discontinued. Actions to achieve this aim include prioritizing the implementation of measures for uses that can result in substantial direct releases to the environment. PFASs-containing fire-fighting foams are proposed to be collected and destroyed after being used (with some exemptions).

41. Establishment of environmental monitoring activity will be necessary to oversee the efficiency of the control measures implemented.

2.2.1 Technical feasibility

42. The limited information available on intentional uses of PFHxS, its salts and PFHxS-related substances indicate that these are similar to PFOS. The report on the assessment of alternatives to perfluorooctane sulfonic acid (PFOS), its salts and perfluorooctane sulfonyl fluoride (PFOSF)" (UNEP/POPS/POPRC/14/4 and UNEP/POPS/POPRC/14/INF/8) indicate that technical feasible alternatives are available for all applications, suggesting the switch to chemical and non-chemical alternatives are feasible. From the POPRC-process on PFOS and their related substances, information from industry indicate that a substitution process is ongoing and only a few critical time-limited uses are identified. For PFOS, these are related to mist suppression in hard metal plating in a closed loop and insect baits for control of leaf cutting ants. For PFOA several time-limited exemptions are proposed (UNEP/POPS/POPRC/14/6/Add.2), but also here transition to other chemical and non-chemical substitutions is ongoing.

43. As set out in section 2.3, there are a wide number of non-fluorinated chemical alternatives for all possible uses of PFHxS, its salts and PFHxS-related compounds including some technical solutions.

2.2.2 Cost and benefits of implementing control measures

44. As there are no critical uses identified and no requests for exemptions it is anticipated that there is no cost associated with the implementation of control measures on production and use. As the costs of remediating PFASs from drinking water is known to be very high, control measures on PFHxS would contribute to avoid such costs.

2.3 Information on alternatives (products and processes) where relevant

45. In general terms there is a lack of published data on the identity and properties of the alternatives to PFAS for most applications because the data usually are protected by confidential business information. Despite several attempts, this document confirms the unwillingness of the industry to share information about production and use of PFHxS (Norwegian Environment Agency M-961/2018, add reference for restriction dossier when available). This assessment of alternatives to PFHxS is therefore based on the general uses mentioned in the Risk Profile (UNEP/POPS/POPRC.14/6/Add.1) and the assumption that the functions of PFHxS in these uses are the same or very similar to that of PFOS and in some cases PFOA.

46. As mentioned above, the identified intentional uses of PFHxS, its salts and PFHxS have been in; (1) AFFFs for firefighting; (2) metal plating; (3) textiles, leather and upholstery; (4) polishing agents and cleaning/washing agents; (5) coatings, impregnation/proofing (for protection from damp, fungus, etc.); and (6) within the manufacturing of electronics and semiconductors.

47. Annex F information submitted by the UK reported that a waste company responded to the request for information that the substance is used in textiles, carpet protectors, leather, papermaking, pesticides, electroplating, firefighting foams, photosensitive material and some synthetic materials. It has also been found in printing inks, sealants and in non-stick cookware. Although they do not use or produce the chemical as a raw product, it is assumed that there will be some embedded in everyday materials (UK Annex F submission).

2.3.1 Application-specific alternative substances

48. Alternatives to PFHxS include substitute chemicals and alternative techniques including non-chemical alternatives such as design or product changes. All effort should be made to ensure substitution with other persistent and/or toxic chemicals is avoided.

49. Regrettable substitution has been defined as occurring “when a toxic chemical is replaced by another chemical that later proved unsuitable because it, too, turned out to be a persistent, bioaccumulative and toxic (PBT) substance, or because of other concern” (US National Research Council, 2014). Reducing the likelihood of regrettable substitution for PFASs is challenging because this is a large class of chemicals containing as many as 4730 substances (OECD 2018). In many cases, long-chain PFASs can be replaced by short-chain PFASs and other fluorinated alternatives which are considered safe by the industry (Fluorocouncil 2015), but although PFASs with shorter chain are in general less bioaccumulative, they are persistent and have higher water solubility and high mobility.

50. Many of the alternative PFASs are suspected to have negative effects on human health and the environment (Gomis et al., 2018). Short-chain PFAS (defined as C₂-C₇ perfluorocarboxylic acids (PFCAs) and C₃-C₅ PFSA) contributed to over 80% of the detectable PFASs in rain samples and the C₂-C₃ PFASs alone accounted for over 40% of the total in rain and water samples in Toronto (Yeung et al., 2017). Novel fluorinated compounds have emerged on the market to replace the long-chain PFASs. Occurrences of several PFECAs and PFESAs, including hexafluoropropylene oxide dimer and trimer acids (HFPO-DA and HFPO-TA), ammonium 4,8-dioxa-3 H-perfluorononanoate (ADONA), chlorinated polyfluorinated ether sulfonic acid (6:2 Cl-PFESA), and its hydrogen-substituted analogue (6:2 H-PFESA) have been observed in surface waters worldwide (Pan et al., 2018). ADONA has also been detected in human blood in populations receiving tapwater contaminated with the substance (Fromme et al., 2017). Contamination of water sources with short-chain PFASs has been observed (Strynar et al., 2015; Gebbink et al., 2017; Braunig et al., 2019). Several short-chain alternative substances are currently under substance evaluation under REACH suspected as PBT or vPvB substances (e.g ADONA, PFHxSA and PFHpA-related substance etc. (CoRAP list ECHA)). Furthermore, these compounds are often less efficient in the application resulting in use of larger volume and increased emissions from the user- and disposal-phase of the product. Over 200 scientists have signed the "Madrid Statement" calling for global phase-out of all PFASs (Blum et al., 2015) and in addition the "Zurich statement on the future action on PFASs" has been published (Ritscher et al., 2018). The Zurich statement paper is a result of a workshop that was held in 2017, and it contains a number of recommendations for the future assessment and management of PFASs (Ritscher et al., 2018).

51. POPRC has previously addressed the issue of regrettable PFAS substitutes for both PFOA and PFOS in the recommendations for alternatives to PFOS (Annex I, decision POPRC-14/3 in UNEP/POP/POPRC.14/6) and the recommendations for the global regulation of PFOA (Annex I, decision POPRC-14/2 in UNEP/POP/POPRC.14/6) under the Stockholm Convention. The alternative short-chain PFASs show relatively higher water solubility and increased environmental mobility and are therefore not recommended as alternatives (See section below; Baduel et al., 2017; Barzen-Hanson and Field, 2015). To avoid regrettable substitution to other perfluoro alkyl substances (PFAS), this section focusses on non-fluorinated chemical alternatives and non-chemical alternative techniques. Only in exceptional cases, such as for fire-fighting foam and metal plating, have fluorinated chemical alternatives been considered.

52. Table 3 gives an overview of the identified use categories and the available alternatives followed by separate sections with information on each application and its alternatives.

Table 3. Overview of alternatives

Application	Alternative available	Type of alternative
Fire-fighting foam	Yes	Non-fluorinated chemical and fluorinated
Metal plating	Yes	Chemical alternatives (non-fluorinated and fluorinated), and technical solutions
Textiles	Yes	Non-fluorinated chemical and technical solutions
Polishing, cleaning- and washing agents	Yes	Non-fluorinated chemical alternatives
Coating, impregnation/proofing	Yes	Non-fluorinated chemical alternatives
Electronic and semiconductors	Yes	Non-fluorinated chemical alternatives
Paper and packaging	Yes	Non-fluorine containing products (and alternative techniques e.g. high-density paper)
Pesticide	Yes	To be added

2.3.1.1 Fire-fighting foam (AFFF)

53. Aqueous film-forming foams (AFFF) are highly effective foam intended for fighting high-hazard flammable liquid fires. AFFF produce a thin layer separating highly flammable liquid or combustible solids from the oxygen rich air. The water film, which is located between the fuel and the foam, cools the surface of the fuel, acts as a vapor

barrier, and supports the spreading of the foam on the fuel. AFFFs are typically formulated by combining synthetic hydrocarbon surfactants with fluorinated surfactants and are normally used as Class B firefighting foams formulated to extinguish liquid hydrocarbon fuel fires. The fluorinated foams in this class are called AFFF, fluoroprotein foams (FP) or film-forming fluoroprotein foams (FFFP). The fluorine-free (F3) Class B firefighting foams are based on proprietary mixtures of hydrocarbon surfactants.

54. PFHxS and PFHxS-related precursors have been measured in AFFF (D'Agostino and Mabury 2014; KemI, 2016; Favreau et al., 2017) and have been detected in ground impacted by AFFF training activity (Barzen-Hanson et al., 2017; Gobelius et al., 2018; Banzhaf et al., 2017). Furthermore, due to the long shelf-life of 10-20 years of AFFF concentrates, stocks of already installed AFFF may still contain PFHxS. In addition some new AFFF produced in China contain PFHxS (https://www.switchmed.eu/en/documents/huang_pfos-substtution-in-china.pdf). According to Eurofeu (2018), the firefighting foam industry has fully implemented the USEPA Stewardship program with a total phaseout of C₈-based AFFF, indicating that fluorinated foams manufactured up to 2015 may contain C₈ perfluorinated substances, after that C₆ Pure has been implemented. C₆ Pure foam contains telomer-based fluorosurfactants (and thus not PFHxS) (FFFC, 2017).

55. The perfluorinated substances (such as PFOS and PFHxS) used in AFFFs have been produced using electrochemical fluorination (ECF), with hydrogen fluoride used as a feedstock alongside organic material (Buck et al., 2011). The ECF production of fluorinated substances may produce both branched and linear products as well as different chain length (Buck et al., 2011). Since PFOS products may contain 1-10% PFHxS (Wang et al., 2017) unless it is cleaned-up and the unintentional PFHxS removed, a complete phaseout of AFFF containing PFOS will also contribute to reduce the emission of PFHxS and PFHxS-related compounds to the environment. Fire-fighting foam is listed as an acceptable purpose for the production and use of PFOS, its salts and PFOSF in Annex B. The recommendation from POPRC-14 (Annex I, decision POPRC-14/3 in UNEP/POP/POPRC.14/6) to COP-9 is to amend the acceptable purpose for the production and use of PFOS, its salts and PFOSF for fire-fighting foam to a time-limited specific exemption for the use of fire-fighting foam for liquid fuel vapour suppression and liquid fuel fires (Class B fires) already in installed systems, including both mobile and fixed systems. The same conditions will also apply to perfluorooctanoic acid (PFOA), its salts and PFOA-related compounds used in AFFF (see Annex I, decision POPRC-14/2 in UNEP/POP/POPRC.14/6 for details).

Alternatives to PFHxS in foam for Class B fires

56. There are two key categories of alternatives to consider in this section, a) non-fluorine alternatives and b) short-chained fluorinated alternatives.

a) Non-fluorine alternatives:

57. Several fire-fighting foam manufacturers provide fluorine-free foams that can meet Class B standard firefighting performance certifications applicable to AFFF and related foams (see Table 6 in UNEP/POP/POPRC.14/6). The only exception is the US Mil Spec, that does not only relate to performance standards but also requires the inclusion of fluorochemicals (MIL-F-24385). On 3 October 2018, the US Senate approved a five-year reauthorization for the Federal Aviation Administration which changed performance standards for firefighting foams to allow the use of fluorine-free foams at civilian airports (US Congress, 2018).

58. Fluorine-free foams have been phased in at civilian airports in Australia, Denmark, Norway, Sweden, and at major hub airports e.g. London Heathrow and Gatwick, Dubai, Stuttgart, Edinburg, Auckland (IPEN, 2018). In Norway, several military properties have phased in fluorine-free-foams. In addition, the offshore oil and gas sector are in the process of phasing in fluorine-free foam in Norway, and the sector is satisfied and confident in its performance.

59. The Institute for Fire and Disaster Control Heyrothsberge in Germany tested six fluorine-free alcohol resistant fire-fighting foams and one PFAS-containing foam for their ability to extinguish fires of five different polar liquids that can be constituents of biodiesel (Keutel and Koch, 2016). The authors conclude that there are fluorine-free foams available which show a similar performance compared with PFAS-containing foams. Also noted in the PFOA RME, the State of Queensland (2016) in Australia, report that many fluorine-free foams are acknowledged as meeting the toughest fire-fighting standards and exceeding film-forming fluorinated foam performance in various circumstances and that fluorine-free foams are widely used by airports and other facilities including oil and gas platforms.

60. LASTFIRE, which is a consortium of 16 oil companies, initiated a project in the late 1990s to review the risks associated with large diameter (greater than 40m) open top floating roof fuel storage tanks. In 2018 LASTFIRE tested 6 new C₆ pure AFFF and two fluorine-free foams on large scale tanks, and from their experiences, it was concluded that no new generation foam (either fluorinated or fluorine-free) can be considered as a straightforward 'drop in' replacement for any formulation previously in use. The consideration of the viability of alternatives needs to consider both fire-fighting performance and compatibility with existing system control and application methods. It is suggested that performance capability of alternative foams will be specific to a formulation and the type of application equipment used. Hence it is not possible to state if all C₆-fluorinated alternatives perform better than all fluorine-free alternatives and vice versa (Ramsden, 2018).

61. There is relatively little publicly available information on the chemical structure or properties of the AFFF products containing non-fluorinated alternatives. A number of manufacturers and commercial products of safety certified fluorine-free foams have been identified, where the details of the precise formulations are not divulged due to confidential business information (see Table 6 in UNEP/POP/POPRC.14/6).

62. Oosterhuis et al. (2017) provided cost estimate data for the substitution of persistent organic pollutants, including PFOS, to safer alternatives. It was indicated that for fire-fighting foam, alternatives appeared to be available at limited additional cost, in some cases close to zero or even negative but always less than €1,000 per kilogram. However, it is indicated that removal and destroying PFOS that are present in existing products, such as firefighting system, is estimated to be well below € 1,000 per kilogram, although it can be higher in individual cases. Removal of PFOS from the environment is costly and could be well over \$10,000 per kilogram (see chapter 2.2.4 for more information on remediation costs).

b) Short-chain fluorinated alternatives:

63. According to the Fire Fighting Foam Coalition (FFFC, 2017), all modern AFFF agents contain fluorotelomer-based fluorosurfactants, and the short-chain (C₆) fluorosurfactants have been the predominant fluorochemicals used in fluorotelomer-based AFFF for the last 25 years. Telomerisation which is a second important process for manufacturing perfluorinated substances, makes a product that normally contains 2 non-fluorinated carbons before the side-group (Buck et al., 2011), and e.g 6:2 FTS are known to degrade to PFHpA and PFHxA and not PFHxS (Wang et al., 2011). There are several Class B certified AFFF on the market based on fluorosurfactants made by telomerisation (see Table 5 in UNEP/POP/POPRC.14/6).

64. The aquatic environment, both surface – and groundwater are in many regions polluted with PFASs and PFHxS and consequently pose a risk to both the human health and the environment. Fire training sites where PFAS-containing AFFFs have been used (often located at airports and military training grounds) have been recognized as one of the major PFAS-contamination sources (Gobelius et al., 2018; Banzhaf et al., 2017; Hu et al., 2016; IPEN 2018). Impact on the environment and the remediation costs are high at these hot spot sites. Furthermore, the alternative short chain-PFAS with <C₇ PFCAs or <C₆ PFSA (including their precursors) show relatively higher water solubility and increased environmental mobility (Baduel et al., 2017; Barzen-Hanson and Field, 2015). There is also increased focus on "Cradle to Grave approach" (Ramsden, 2017). Recognition of these facts led to the following recommendation to COP-9 from the POPRC-14; "The Committee recognized that a transition to the use of short-chain per- and polyfluoroalkyl substances (PFASs) for dispersive applications such as fire-fighting foam is not a suitable option from an environmental and human health point of view and that some time may be needed for a transition to alternatives without PFASs.

65. Best practice guidelines have been developed by the foam industry (FFFC, 2016) for use of fluorine containing foam:

(a) "Fluorinated Class B foams should only be used in situations that present a significant flammable liquid fire hazard.

(b) Before deciding to use fluorinated Class B foam for a specific hazard, investigate whether other non-fluorinated techniques can achieve the required extinguishment and burn-back resistance.

(c) The use of Class B foam is not recommended for Class A (wood) or Class C (electrical) hazards where there is minimal or no flammable liquid fire threat. If a flammable liquid threat exists, Class C applications must be de-energized since foam contains water that can conduct electricity. Examples of situations where Class B foams are not required include but are not limited to forest fires, residential and structural fires, computer rooms and telecommunications facilities, restaurants and commercial kitchens, and general facilities protection. In addition, Class B foams may not be necessary for small flammable liquid fire threats such as automobile fires without a significant fuel spill where a large water application rate or dry chemical extinguisher can be used. Training and testing should be done with fluorine free foams only.

(d) Use surrogate liquid test methods that do not contain fluorosurfactants for testing fixed system and vehicle foam proportioning systems".

66. In addition, they recommend that firewater should be retained and treated appropriately.

2.3.1.2 Metal plating

67. During assessment of alternatives to PFOS several alternatives, including non-fluorinated chemical alternatives and technical solutions, were discussed (see Table 3 in UNEP/POPS/POPRC.14/INF/8).

68. Metal plating (hard metal plating) only in closed-loop systems is listed as an acceptable purpose for the production and use of PFOS, its salts and PFOSF in Annex B under the Stockholm Convention. Hard metal plating is used to protect metal components from wear and corrosion. Industrial rollers, hydraulic cylinders and crankshafts are examples of industrial applications of hard chromium electroplating. Through the electroplating process, a thin layer

of chromium is deposited on the base metal or metal alloy surface of a workpiece where resistance and hardness are important attributes. In these applications the workpiece is submerged in a chromic acid (hexavalent chromium) bath. Fume suppressants are chemical agents added to the chromium bath to reduce the amount of chromium lost at the surface. Chemical fume (mist) suppressants are surfactants that lower the surface tension of the plating solution and by controlling the surface tension, the process gas bubbles become smaller and rise more slowly than larger bubbles and mist is less likely to be emitted into the air and the droplets fall back into the plating bath.

69. It is not clear from the publicly available information on PFHxS how extensively the substance is used in metal plating but PFHxS and its related compounds are recommended for this use (see section 2 "Summary information relevant to the risk management evaluation"). Due to unintentional production of PFHxS during the ECF process (Wang et al., 2017), it is likely that the PFOS-containing mist/fume suppressants used for metal plating contain unintentional amounts of PFHxS, its salts and/or PFHxS-related compounds. Furthermore, a number of patents (Dainippon, 1979, 1988; 3M, 1981; Hengxin, 2015) were identified for the use of PFHxS, its salts and various PFHxS-related compounds in metal plating as mist suppressants, suggesting that such use may have occurred. It is likely that at least Hubei Hengxin in China has marketed the potassium salt of PFHxS for metal plating and PHxSF as a raw material for electroplating (Hengxin, 2019). Furthermore, it should be noted that the manufacturing (including importing) or processing of one salt of PFHxS (tridecafluorohexanesulfonic acid, compound with 2,2'-iminodiethanol (1:1); CAS No: 70225-16-0) for use as a component of an etchant, including a surfactant or fume suppressant, used in the plating process to produce electronic devices shall not be considered a significant new use subject to reporting under the USEPA Significant New Use Rule on perfluoroalkyl sulfonates and long-chain perfluoroalkyl carboxylate chemical substances (USEPA, 2013).

Non-chemical alternative techniques

70. Some alternative technologies that omit the use of chemicals and prevent Cr(VI) release during plating processes are available (Table 3 in UNEP/POPS/POPRC.14/INF/8). These include the use of PTFE-coated balls on top of the bath, and mesh or blanket covers for plating baths. However, the effectiveness of this approach relative to mist suppressants has been questioned (see Section 2.5.3 in UNEP/POPS/POPRC.14/INF/8). There is also the use of control devices, such as Composite Mesh Pads (CMP) or Chromic Acid Fume Scrubber (<https://www.monroenvironmental.com/air-pollution-control/packed-bed-wet-scrubbers/>) to catch aerosols from chromium plating. According to the BAT/BEP Guidance for use of PFOS (UNEP/POPS/POPRC.12/INF/15/Rev.1.) these techniques are considered alternatives to the use of PFOS-based control devices and it has been indicated that there are no factors limiting the accessibility of these control devices, and they are commercially available in Canada (UNEP/POPS/POPRC.12/INF/15/Rev.1.). The composite-mesh-pad (CMP) system collects and transports chromium emissions through a mesh blanket-type pad where the chromium particles are condensed and collected, primarily through physical means. A CMP system typically consists of several mesh-pad stages. Early stages remove large particles, intermediate stages remove smaller particles and final stages remove microscopic particles. The CMP system is effective at removing droplets and eliminating the discharge of chromic acid mist.

Chemical alternatives

71. The following alternatives to PFOS (and PFHxS) are discussed and/or used: 1. Fluorinated substitutes: As to their uses, these substances are comparable with PFOS, and they can be used in almost all processes including chromo-sulfuric acid etchant, bright chromium and hard chromium electrolytes. The fluorinated substitutes can be divided into three sub-groups: i. short-chain fluorinated surfactants, ii. polyfluorinated surfactants; and iii. polyfluorinated compounds. 2. Fluorine-free substances: These have already been partially used in bright chrome electrolytes. According to some suppliers of process chemicals, their use in hard chromium electrolytes is also possible. According to the current state of knowledge, the use of such substances should be considered on a case-by-case basis (For details see UNEP/POPS/POPRC.14/INF/8).

72. Poulsen et al. (2011) have demonstrated that it is possible to use PFOS-free mist suppressants for nondecorative hard chromium plating (chromium VI) in closed loop systems. Attempts to use Cr (III) also for hard chromium plating are also ongoing: "Trion Coatings LLC, which incubated at Notre Dame's IDEA Center, was formed for developing an environmentally friendly alternative to hexavalent chromium in chrome plating. Its patent-pending process uses trivalent chromium salts and a proprietary ionic liquid solution that is said to offer faster electroplating speeds, improved wear resistance and overall higher performance results than traditional hexavalent chrome, while also offering an excellent health and safety profile" (<https://www.pfonline.com/blog/post/nucor-invests-in-environmentally-friendly-chrome-plating>).

2.3.1.3 Textiles including leather and upholstery

73. Finishing agents based on polyfluoroalkyl substances (PFAS) are widely used in textiles to achieve water, oil and dirt repellency of the material, while at the same time maintaining breath-ability. According to Hubei Hengxin, the PFHxS-related compound [N-methyl-perfluorohexane-1-sulfonamide] ethyl acrylate (CAS No: 67584-57-0) is used in oil repellent- and water repellent products for leather and textile (Hengxin 2019). The use of PFAS in textile production accounts for about 50% of global use of PFAS (Danish EPA, 2015). According to a study performed by

the Danish Government (Danish EPA, 2015) five alternative non-fluorinated chemical groups are mentioned in the report; 1) paraffins, 2) stearic acid-melamine, 3) silicone, 4) dendrimers and 5) nano-material. The report concluded that non-fluorinated alternatives, which provide durable water repellence are available, but that non-fluorinated chemical alternatives for oil and dirt repellence are limited (Danish EPA, 2015). A range of fluorocarbon-free, water-repellent finishing agents for textiles include commercial products such as BIONIC-FINISH®ECO and RUCO-DRY® ECO marketed by Rudolf Chemie Ltd., Geretsried/Germany; Purtex® WR, Purtex® WA, Purtex® AP marketed by the Freudenberg Group, Weinheim/Germany; and ecorepel® marketed by SchoellerTechnologies AG, Sevelen/Switzerland. Also, textile and carpet surface treatment applications based on acrylate, methacrylate and adipate are available (UNEP/POPS/POPRC.13/7/Add.2.).

74. A consumer study investigating variation in functionality between long-chain (C₈) PFAS repellent chemistry, shorter-chain (C₆) PFAS repellent chemistry, and non-fluorinated repellent chemistry within outdoor apparel fabrics aimed to report a novel comparison of currently commercially available repellent fabrics for outdoor apparel as well as an assessment on their repellent functionality both for water and oil resistance (Hill et al., 2017). For outdoor apparel consumers, non-fluorinated chemistry can currently meet the water repellence requirements. The authors propose that the use of PFAS chemistry for outdoor apparel is therefore over-engineering, providing oil repellence that is in excess of consumer requirements. In a different study, side-chain fluorinated polymers (SFPs) and non-fluorinated water repellent agents based on polydimethylsiloxanes or hydrocarbons showed excellent water repellence and durability in some cases while short-chain SFPs were the more robust of the alternatives compared to long-chain SFPs in terms of water repellence (Schellenberger et al., 2018). A strong decline in oil repellence and durability with perfluoroalkyl chain length was shown for SFPs. Non-fluorinated alternatives were unable to repel oil, which might limit their potential for substitution in textile applications that require repellency towards non-polar liquids (Schellenberger et al., 2018). This is in line with information provided in the assessment of alternatives to PFOS that was updated in 2018 (UNEP/POPS/POPRC.14/INF/8).

75. As an alternative to chemical treatment of textiles, tightly woven fabric has been proposed as an alternative. Furthermore, PFAS-free fabric for furniture such as C-Zero that are stain resistant are available (<https://www.crypton.com/>).

2.3.1.4 Polishing agents and cleaning/washing agents

76. There is not much publicly available information on the use of PFHxS in cleaning-, washing- and/or polishing products. One PFHxS-related compound (CAS No: 67584-53-6, [N-Ethyl-N-(tridecafluorohexyl) sulfonyl]glycine, potassium salt) was reportedly used in polishing agents and cleaning/washing agents at least between 2000 and 2015 in Denmark, Norway and Sweden (SPIN, 2018). For example, the FCP102 Floor Sealer and FCP300 Duro Gloss Floor Sealer & Finish from Fritztile contain this compound (Fritztile, 2018a,b). Fluorine-free products can perform this function. For example, Impregno stone impregnato is a fluorine-free waterproofing protection, fluorine/PFC-free, waterproof/dirt repellent (<https://www.amazon.co.uk/Impregnator-Fluorine-Free-Waterproofing-Protection-Environmentally/dp/B015CHR378>).

2.3.1.5 Coatings, impregnation/proofing (for protection from damp, fungus, etc.)

77. One PFHxS-related compound (CAS No: 67584-61-6, 2-[Methyl[(Tridecafluorohexyl) Sulfonyl]Amino]Ethyl Methacrylate) was reportedly used in impregnation/proofing for protection from damp, fungus, etc. at least in four products between 2003 and 2009 in Denmark (SPIN, 2018). FluoroCouncil (in UNEP-POPS-POPRC.14-INF-8) has reported large number of global suppliers are offering “non-fluorinated” alternatives, including:

- (a) Hydrocarbon wax-based repellents consisting of paraffin-metal salt formulations;
- (b) Hydrophobic modified polyurethanes (hydrophobic modified hyper-branched polyurethanes called dendrimers);
- (c) Polysiloxane-based products;
- (d) Resin-based repellents consisting of fatty modified melamine resins.

2.3.1.6 Manufacturing of electronics and semiconductors.

78. PFOS has been used in the semi-conductor industry for applications including photo-resists, and anti-reflective coatings (ARCs) for semiconductors and etching agent for compound semi-conductors and ceramic filters, which are listed as acceptable purposes for the production and use of PFOS, its salts and PFOSF in Annex B. Several studies have reported release and emission of PFHxS from the semiconductor industry (reviewed in the risk profile for PFHxS; UNEP/POPS/POPRC.14/6/Add.1) indicating that PFHxS has been substituted for PFOS in this application. It has been indicated that PFHxS is used in the washing process in semiconductor manufacture (<http://koreajoongangdaily.joins.com/news/article/article.aspx?aid=3049751>). Investigations revealed that PFHxS was the main PFAS constituent in the final waste effluent from a semiconductor fabrication plant (Lin et al., 2009). This information is further strengthened by published information that indicates that PFHxS is used in the semiconductor industry in Taiwan province of China. PFHxS (133,330 ng/L), together with PFOS (128,670 ng/L), was one of the

primary contaminants at a semiconductor fabrication plant waste water effluent site. Both PFASs are present in the effluent in similar amounts showing that PFHxS is a primary substance in this process and not unintentionally present at this site (Lin et al., 2010). PFAS (e.g. PFOS or PFHxS) does not remain in the semiconductors but in the case where PFAS was not removed from the waste water before it is released, it will follow the waste water and be released into the environment. There is no other available information on what specific processes in the manufacture of electronics and semiconductors that PFHxS is used and it is therefore necessary to review all the information available on alternatives to PFOS within the manufacture of electronics and semiconductors. According to the guidance on alternatives to PFOS (UNEP/POPS/POPRC.9/INF11/Rev.1) small amounts of PFOS-based compounds are required during the following critical photolithography applications in manufacturing semiconductor chips:

- (a) Ultra-fine patterning/photo resists as photo-acid generators and surfactants;
- (b) Anti-reflective coatings as uniquely performing surfactants.

79. PFHxS, like PFOS can be used as a surfactant in the manufacture of compound semiconductors and rinsed out during the subsequent washing treatment. Several non-fluorinated chemical alternatives were identified during the assessment of alternatives to PFOS (UNEP/POP/POPRC.14/INF8/Add.1). The following alternatives were classified as potentially not to have POP-characteristics; amyl acetate, anisole, n-butyl acetate, ethyl lactate, methyl-3-methoxypropionate and propylene glycol methyl ether acetate. The scientific literature indicates that it should be possible to develop a PFOS-free photo-resist system (Ayothi et al., 2006). Also, some patents describe fluorine-free photoresist compositions as alternatives to PFOS/PFAS use (see UNEP/POPS/POPRC.12/INF/15/Rev.1). In 2010, IBM announced a fluorine-free photo-acid generator as part of their PFAS phase-out and IBM notes that the fluorine-free process meets performance requirements for both dry immersion exposures (<https://www.spiedigitallibrary.org/conference-proceedings-of-spie/7639/1/Design-synthesis-and-characterization-of-fluorine-free-PAGs-for-193/10.1117/12.846600.short>).

2.3.2 Other uses

80. In addition to the above-mentioned applications, information from various sources indicates that PFHxS is used in sealants, adhesives, architectural foam, and coatings as well as in some applications in buildings and construction. In addition, information on applications such as to coat frying pans and to kill pests in addition to the known use in the semiconductor industry, has been published on the web (<http://koreajoongangdaily.joins.com/news/article/article.aspx?aid=3049751>). The released information indicates that in some regions PFHxS, its salts or PFHxS-related compounds have replaced the use of PFOA in cook wear and that PFHxS substances have replaced the PFOS-related substance sulfluramid in pest control.

81. The Imaging and Printing Association Europe (I&P Europe) which includes all the major manufacturers of photographic products (photo-imaging industry and photographic industry) within the European Union, notified that their members are not using PFHxS, its salts or related compounds (I&P Europe Annex F information).

2.4 Summary of information on impacts on society of implementing possible control measures

82. A positive impact on human health and the environment can be expected from a global reduction or elimination of PFHxS, its salts and PFHxS-related compounds. It is decisive to take into account the specific characteristics of PFHxS when assessing the human health and the environmental impacts of restriction. These substances are considered POPs and therefore have defined properties. These are in particular related to the potential of PFHxS to persist in the environment, which means that it is not removed from the environment. Therefore, PFHxS is present in the environment on a global scale, also in remote areas where emissions are negligible. In addition, PFHxS has the potential to accumulate in living organisms as well as having toxicological properties, that may lead to adverse effects on human health and the environment arising from long-term exposure. PFHxS also has the longest half-life in human serum ever reported for any PFAS. Therefore, the risk management of these substances is driven by scientific data and precautionary action in line with the objective of the Stockholm Convention to avoid potentially severe and irreversible impacts resulting from continued emissions.

2.4.1 Health, including public, environmental and occupational health

83. The elimination of production, use, export, and import of PFHxS and PFHxS-related compounds through a listing in Annex A without exemptions would positively impact human health and the environment by decreasing and ultimately eliminating emissions. As outlined in the risk profile, PFHxS has widely contaminated the environment including humans and wildlife (UNEP/POPS/POPRC.14/6/Add.1). PFHxS displays a broad range of toxic impacts including negative effects on liver function, lipid and lipoprotein metabolism; endocrine disruption; alterations in serum cholesterol, lipoproteins, triglycerides, and alkaline phosphatase; effects on reproduction; and may affect the developing brain and immune system. Effect on the antibody response to vaccination has been shown in epidemiology studies. It is found in blood, urine and breast milk. PFHxS has a very long half-life time in humans (Olsen et al., 2007) and is passed from one generation to the next via breast milk and in utero.

84. Drinking water has been identified as an important source of human exposure, and in areas with contaminated drinking water, increasing trends are observed in human blood levels of PFHxS (Li et al., 2018). Due to the

widespread use of PFAS in AFFF and historical, and in some countries, continuing practice of training in the open field in combination with the persistency of PFAS, drinking water sources have been contaminated in many countries on all continents (Gobelius et al., 2018; Banzhaf et al., 2017; Mak et al., 2009; Kabore et al., 2018; Zafeiraki et al., 2015; Boiteux et al., 2012; Ericson et al., 2009, see Table 1.6 in UNEP/POPS/POPRC.14/INF/4 for details). In 2010–2015, PFHxS was detected in drinking water in 23 US States among 134 water utilities serving 5.5 million people (EWG's Tap Water Database). PFHxS was detected in more than 200 samples from >5000 public water systems screened for PFASs in the USA (Guelfo and Adamson, 2018).

85. To protect their inhabitants, limit values for some PFAS in drinking water has been set in many countries (see previous paragraph 1.5). In 2014, the Swedish Chemicals Agency and the Swedish Food and Drug Administration initiated a national PFAS network for authorities, researchers, county administrative boards, municipalities and water producers. The network focuses on addressing the problem of PFASs in drinking water and discuss solutions to remove the substances from the soil and in drinking water, but also for more initiatives including research on perfluorinated substances. The network is a platform for communicating contacts and supporting various actors in the country (KemI, 2014).

86. Traditional water treatment techniques such as ferric or alum coagulation, granular/micro-/ultrafiltration, aeration, oxidation (i.e., permanganate, ultraviolet/hydrogen peroxide), and disinfection (i.e., ozonation, chlorine dioxide, chlorination, and chloramination) are mostly ineffective in removing PFASs (Boone et al., 2019). The water treatments methods for disinfection such as chlorination and ozone treatment have been shown to degrade precursors from a group of four zwitterionic/cationic polyfluoroalkyl amide and sulfonamides to PFOA and PFOS (Xiao et al., 2018). In some water treatment plants, slightly higher levels of PFASs have been observed in the treated drinking water relative to the water source indicating generation from precursors (Boone et al., 2019). Increased levels of PFASs have also been observed in efflux compared to influx in waste water treatment plants (WWTP). Perfluorohexanoic acid (PFHxA), PFOA, PFHxS, and PFOS had a net mass increase in efflux compared to influx in all WWTPs, with mean increases of 83%, 28%, 37% and 58%, respectively (Eriksson et al., 2017).

87. Some techniques have proven efficient in removing PFAS from water (although of high cost see 2.4.4). These techniques could also be used on WWTP effluents to reduce emissions to the environment. PFHxS had greater than 95% removal by nanofiltration in deionized water when artificial groundwater and a fouling layer were present on the filtration membrane, which more accurately represents a real-world scenario. Micro- or ultrafiltration coupled with reverse osmosis has shown to remove targeted PFAS, including PFHxS. Although less effective on several other short-chained PFAS compounds, ion exchange resin can effectively remove >97% of PFHxS (reviewed in Arvaniti and Stasinakis 2015). Anion exchange and granular activated carbon (GAC) treatment preferably removed longer-chain PFASs and the PFASs compared to the PFCAs, and reverse osmosis demonstrated significant removal for all the PFASs, including the smallest PFAS as perfluorobutanoic acid (Appleman et al., 2014). Furthermore, both GAC and anion exchange (AE) have been shown to have a higher removal efficiency of linear compared to branched PFASs, indicating that designers and operators of AE and GAC treatment processes must take into consideration the selective nature of PFAS removal and associated desorption of short-chain PFCAs during co-removal of multiple PFASs (McCleaf et al., 2017).

88. Dust has been identified as an important source of exposure, especially for occupational exposure, but also for toddlers, which due to their hand to mouth behaviour has an elevated exposure to dust. At a Chinese fluorochemical manufacturing plant for PFOS-related compounds, indoor dust (67.3%) and diet (31.6%) were found to be the largest sources to human PFHxS exposure (Gao et al., 2015). Serum concentrations of PFHxS were in the range 12.8–10,546 ng/mL, and indoor dust levels rang from nd-257,201 ng/g (mean = 15726) (Gao et al., 2015). In another study from a fluorochemical manufacturing plant in the same district, serum concentrations of PFHxS in family members of occupational workers were in the range 4.33–3,164 ng/mL, dust in residences connected to the plant had PFHxS in the range 0.44 to 708 ng/g, both significantly higher than in ordinary residents in the plant area, diet PFHxS was in the range 0.067–0.448 ng/g ww and drinking water PFHxS from n.d to 3.2 ng/L (Fu et al., 2015). Strict procedure for equipment and changing protection-clothing in different zones could immediately reduce the exposure, and a ban of PFHxS its salts and related compounds would have a greater effect long term.

89. Firefighters would also benefit from a ban of PFHxS, its salts and related compounds. In firefighters, serum levels of PFHxS were in the range of 49–326 ng/mL serum, whereas the control group ranged 0.2–22 ng/mL serum (Rotander et al., 2015).

2.4.2 Agriculture, including aquaculture and forestry

90. No information on direct use of PFHxS, its salts or PFHxS-related compounds as pesticides has been provided. However, there are indications for use in pest control (see section 2.3.2).

91. A phaseout of PFHxS, its salts and PFHxS-related compound would be beneficial for agriculture. Due to the use of PFHxS and other PFAS in several industrial- and household applications the substances are regularly detected in waste water treatment plants (WWTP) and landfill leachates (see Table 1.5 in UNEP/POPS/POPRC.14/INF/4). Air emission of PFHxS from landfills and WWTPs as well as accumulation in leaves around landfills have been reported (Ahrens et al., 2011a; Tian et al., 2018). Research suggests that the spread of PFASs in agricultural soil is mainly a

result of irrigation with contaminated water, the use of polluted sewage sludges or industrial wastes as soil conditioners (Ghisi et al., 2019). PFASs (including PFHxS) are absorbed by plants to different extents according to their concentrations, chain lengths, functional group, plant species and variety, growth media (hydroponics vs. soil), and soil and biosolid characteristics (reviewed in Ghisi et al., 2019). Use of biosolids (treated sludge from WWTP) to fertilise soil can increase levels of PFAS in crops. Uptake in plants of PFHxS from PFAS-spiked soil, has been observed (Wen et al., 2014). Furthermore, plants have been shown to biotransform precursors e.g. wheat has been shown to biotransform PFOSA to PFOS, PFHxS and PFBS (Zhao et al., 2018).

92. As reviewed in the risk profile, a number of studies have reported the presence of PFHxS in food items (EFSA 2012; Gebbink et al., 2015; Noorlander et al., 2011, Food Standards Australia New Zealand, 2016; Table 1.7 in UNEP/POPS/POPRC.14/INF/4). PFHxS has been detected in infant formula and dairy milk (Tao et al., 2008) as well as in duck egg and meat (Cui et al., 2018). PFHxS and other PFAS has been detected in fruits and vegetables from Europe (Herzke et al., 2013 and D'Hollander et al., 2015). In a Spanish study aiming to identify dietary patterns that contribute to human exposure to PFASs (among other substances), meat and fish consumption was positively associated with PFHxS concentrations (Arrebola et al., 2018). Livestock can potentially be exposed to PFAS through the consumption of contaminated surface water, groundwater, pasture, soil and feed. In Australia, environmental samples mainly from contaminated sites found highest mean upper bound PFHxS in cattle meat, rabbit meat and eggs (Food Standards Australia New Zealand, 2016). Other foods with high concentrations were crustaceans, fish liver and sheep meat (Food Standards Australia New Zealand, 2016). Studies on wheatgrass grown on soil contaminated with AFFF showed that PFHxS was bioavailable and bioaccumulated (Braünig et al., 2019). In a study from China, PFBA and PFBS were found to be the major contaminants in both home-produced vegetables and eggs from the residential gardens around a fluorochemical industrial park in Fuxin. In this study, PFHxS was also detected but at a much lower level (Bao et al., 2019).

93. PFHxS has also been shown to be taken up through the roots from contaminated water and soil in silver birch and spruce (Gobelius et al., 2017). The high uptake of PFAS from certain plants such as silver birch and spruce was recently suggested as a low-cost phytoremediation of AFFF impacted ground Gobelius et al. (2017). Recommended threshold values for PFOS and other PFAS in soils have been set by countries, e.g. Swedish Geotechnical Institute has recommended threshold levels for PFOS of 0.003 mg/ kg dw for sensitive land use and 0.02 mg/ kg dw for non-sensitive land use. Since the environment often is impacted by several PFASs threshold recommendations should be expanded to cover more substances (Gobelius et al., 2018).

94. PFHxS has been detected in WWTP outlet and landfill leachates worldwide (Hamid et al., 2018; Arvaniti and Stasinakis, 2015). In a study by Allred et al., 2014, several PFHxS precursors (FHxSAA, MeFHxSAA, EtFHxSAA) were detected in leachates from landfills indicating that these PFHxS precursors and/or their parent compounds may be used in a variety of applications since the landfills had received residential and commercial waste, construction and demolition waste, biosolids from waste water treatment plants as well as non-hazardous industrial waste.

95. PFHxS has been detected in many aquatic species (see Table 1 in UNEP/POPS/POPRC.14/INF/4). A phaseout of PFHxS, its salts and PFHxS-related compound would also be beneficial for aquaculture, especially in areas where aquatic species are an important food source and fish product consumption are shown to be a pathway for exposure to PFHxS for residents. High PFAS and PFHxS serum levels were observed in fishery employees located in Tangxun Lake and residence to Baiyangdian Lake, adjacent to fluorochemical plants (Zhou et al., 2014; Ciu et al., 2018).

2.4.4 Economic aspects and social costs

Prohibition on use

96. Based on information such as price, accessibility and availability of different alternatives as well as information on regulatory measures and use in different countries, the socioeconomic costs of implementing a ban and/ or restriction on the use of PFHxS are considered small and outweighed by the benefits of elimination/ regulation.

97. Both social cost, due to increased anxiety related to health, and economic loss, due to reduction in property value, are high in areas receiving contaminated water or containing contaminated ground. Increasing evidence suggests that fluorochemical contamination of groundwater is an ongoing serious issue impacting agriculture, fisheries, property prices, with considerable political and public concern fallout resulting in hugely expensive and damaging legal challenges. Lifetime costs for using AFFF, fluoroprotein (FP), or film forming fluoroproteins (FFFP) far outweigh those of fluorine-free foams just because of the legal and financial liabilities of using a fluorochemical based foam (see Queensland Gov., 2016a and 2016b).

Control of discharge and emissions

98. The costs related to PFAS contamination of drinking water for two case examples has been estimated to amount to 1 million € per year for charcoal filtering of water in Uppsala and to 3 million € for new water supply in Ronneby, which is a small city where approximately 5000 households were immediately affected when high levels of PFASs were discovered in 2013 (Keml, 2016). In addition, it is a social cost that exposure to PFAS including PFHxS via drinking water causes anxiety in affected populations.

99. Due to the extensive use of AFFF, one of the biggest sources to PFAS, especially PFOS, to the environment is the dispersals from contaminated soils. PFOS has been and is used in AFFF and therefore has been spread in nature around firefighting training sites. In Norway, as well as in many other countries, airports have been especially targeted, as there are obligations to regularly test and practice firefighting. In Norway, 50 airports have been investigated, and PFOS, as well as PFHxS and other PFAS contamination has been identified at a majority of the sites, ranging from low concentrations and small remaining amounts in the soils, to heavily contaminated sites with dispersals to nearby lakes and fjords. Remediation is ongoing at several airports but the exact costs for this remediation solution are still uncertain. The active charcoal (AC)-filters that are suggested to be used, are known to easily get clogged if the water contains e.g. humic substances, something that is expected in the water of this area. Depending on the frequency with which the filters have to be exchanged, the costs for this remediation solution could be up to 50 mil. NOK (6.5 mil US \$). The installation of the water pump- and treat system, is estimated to be 14 mil. NOK (1.8 mil US \$). One of the highest uncertainties for cost estimates is the time frame for PFOS in the soils to be washed out to such an extent that the water in a stream does not have a negative impact on the receiving lake, nor the fjord (Alling et al., 2017).

Waste management and stockpiles

100. The POPRC previously developed a series of recommendations to deal with the PFOS waste stream that are highly applicable to PFHxS. Decision POPRC-6/2 outlines a series of risk reduction measures in a short-term, medium-term and long-term framework. Since the use pattern is similar these recommendations for PFOS (are largely applicable to PFHxS as well) including: "To use best available technique and best environmental practice destruction technologies for wastes containing PFOS in current production and industrial uses of PFOS. No landfilling of these wastes should be permitted, unless leachate containing PFOS is properly treated. To ensure safe storage when destruction technologies are not readily available. To launch urgent investigations into landfills where waste from PFOS producers or from PFOS industrial users (paper, carpet, textile, chromium plating and other industries having used PFOS are deposited. Drinking water from reservoirs and wells in the vicinity of these landfills and also around the PFOS production and user areas should be analyzed".

101. Detailed recommendations are also developed to reduce risk from use, existing stocks, recycling of articles, consumer products deposited in municipal landfills, and releases from contaminated sites (Decision POPRC-6/2).

2.4.5 Movement towards sustainable development

102. Elimination of PFHxS is consistent with sustainable development plans that seek to reduce emissions of toxic chemicals and that links chemical safety, sustainable development and poverty reduction. Environmentally sound management of "toxic chemicals" including waste is part of Agenda 21 and the Rio declaration on environment and development (UNCED 1992a,b). It is also part of the SAICM where efforts are focused on gathering and exchanging information on perfluorinated chemicals and to support the transition to safer alternatives. The Overarching Policy Strategy of SAICM includes POPs as a class of chemicals to be prioritized for halting production and use and substitution with safer substitutes.

2.5 Other considerations

103. Listing PFHxS in Annex A without exemptions will involve control measures that are straight forward to communicate and therefore should be effective and suitable, even in countries that have limited chemical regulatory infrastructure. Information on alternatives is readily available and can be communicated as needed. With regard to environmental monitoring and biomonitoring, PFHxS can be added to existing programmes for monitoring other POPs, particularly PFOS and PFOA. Parties to the Convention, for which any amendments have entered into force, have to meet the obligations under the Convention.

2.5.1 Access to information and public education

104. Several Parties, observers and NGOs have information and public education concerning PFAS on their webpages. e.g.:

- (a) OECD; Portal on per and poly fluorinated chemicals. <http://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/>;
- (b) ECHA; European Chemical Agency. <https://echa.europa.eu/>;
- (c) ATSDR; Agency for Toxic Substances & disease registry. <https://www.atsdr.cdc.gov/pfas/index.html>;
- (d) Australia: <https://www.pfas.gov.au/> and <http://www.defence.gov.au/Environment/PFAS/Publications/Default.asp>;
- (e) Miljø- og Fødevareministeriet Denmark: <https://mst.dk/>;
- (f) Swedish Environmental Protection Agency: [http://www.swedishepa.se/Global-links/Search/?query=PFAS](http://www.swedishepa.se/Global-links/Search/?query=PFAS;);
- (g) Norwegian Environment Agency; <http://www.environment.no/>;

(h) Information related to initiatives under the Canadian Environmental protection Act, 1999: <http://www.ec.gc.ca/lcpe-cepa/default.asp?lang=En&n=1FE509F3-1>;

(i) Information on the assessment and management of substances in Canada: <https://www.canada.ca/en.html>;

(j) The Great states of Alaska: Division of Spill Prevention and Response. Contaminated sites: <https://dec.alaska.gov/spar/csp/pfas-contaminants>;

(k) Access to data generated by FluoroCouncil members: <https://fluorocouncil.com/Resources/Research>;

(l) German Environment Agency: <https://www.umweltbundesamt.de/>;

(m) Swedish Chemicals Agency: www.kemi.se.

2.5.2 Status of control and monitoring capacity

105. PFHxS is included in several ongoing monitoring programs.

106. Canada is monitoring for PFHxS in air as one of the substances under GAPS, the Northern Contaminants Program (NCP) and the Great Lakes Basin (GLB) Monitoring and Surveillance under the Chemicals Management Plan (CMP).

107. Monitoring in human blood, specifically blood plasma, is done in the frame work of the German Environmental Surveys (GerES) and the German Environmental Specimen Bank (ESB). Time trend data on PFHxS is available concerning the years 1982-2010 (Schröter-Kermani 2013). A project is in progress which will add the years 2013-2019 to the time trend analysis (Germany Annex F information). PFASs, including PFHxS, are included in the Swedish Environmental Surveillance Program (Naturvardsverket) and the Swedish health related monitoring program (Karolinska Institutet). PFHxS and other perfluorinated compounds are also monitored in humans in Canada, for example under the Northern Contaminants Program, Canadian Health Measures Survey and Canadian Maternal-Infant Research on Environmental Chemicals.

108. The European Joint Programme HBM4EU, coordinated by the German Environment Agency, has identified per- and polyfluorinated substances as priority substances and will compile EU-wide data on exposure and effect until 2021.

109. Norway has annual monitoring of air, freshwater, marine and terrestrial biota that include PFHxS (www.Miljodirektoratet.no).

110. Listing PFHxS in Annex A with no exemptions would be the most cost-effective option as many countries lack infrastructure to adequately monitor production and uses of PFHxS. Countries that lack the needed infrastructure to adequately monitor production and uses of PFHxS may require additional resources.

3. Synthesis of information

3.1 Summary of risk profile information

111. At its fourteenth meeting in 2018 the POPs Review Committee adopted the risk profile and concluded that PFHxS, its salts and PFHxS related compounds are likely, as a result of their long-range environmental transport, to lead to significant adverse human health and environmental effects such that global action is warranted.

112. PFHxS, its salts and PFHxS-related compounds have been used as surfactants, water- and stain protective coatings for carpets, paper, leather and textiles and in fire-fighting foams among other applications, often as a replacement for PFOS. PFHxS has been unintentionally produced during the ECF processes used in production of e.g. PFOS. Information about current global manufacture of PFHxS, its salts and PFHxS-related compounds is limited. Historical production was mainly carried out by 3M. A few producers located in China have been identified, however quantitative production data are not publicly available.

113. PFHxS is extremely persistent in the environment. Numerous studies have reported elevated levels of PFHxS in soil, water and a variety of biota. Based on a read-across approach from the conclusions applied to the persistence of perfluorobutane sulfonic acid (PFBS), PFOS and PFOA, it can be concluded that PFHxS is not degradable under natural conditions and is very persistent in water, soil and sediment. Furthermore, the PFHxS ion is relatively water-soluble and it binds to proteins in target organisms. Based on the identified protein-binding associated bioaccumulation, standard BCF/BAF in aquatic organisms are less meaningful descriptors for bioaccumulation for PFASs including PFHxS. However, biomagnification does occur, with biomagnification factors (BMFs) and trophic magnification factors (TMFs) >1 (BMF range 1.4–48 and TMF range 0.1–4.3) available for PFHxS, and the estimated serum elimination half-life of PFHxS in humans is higher than other PFASs with an average of 8.5 years (range 2.2-27 years).

114. PFHxS is found ubiquitously spread throughout the environment and in biota globally. A number of studies have reported exposure in remote areas that can be attributed to long-range environmental transport. PFHxS is

detected in water, snow, air and biota (including humans) at remote locations. The main mechanism of transport to remote regions like the Arctic is presently most likely through ocean currents. However, transport of PFHxS and PFHxS-related compounds via the atmosphere cannot be excluded since PFHxS has been measured in snow, rainwater and air as well as in lichen. It is likely that both PFHxS and PFHxS-related compounds are transported through air to remote regions and that PFHxS-related compounds degrade to PFHxS locally.

115. Humans are exposed to PFHxS mainly through intake of food and drinking water but also through the indoor environment via exposure to dust or consumer products containing PFHxS or its precursors. Following PFOS and PFOA, PFHxS is the most frequently detected PFAS in blood-based samples from the general population worldwide. PFHxS is present in the umbilical cord blood and breast milk. Breast milk may be an important source of exposure to breast-fed infants since it is documented that PFHxS is excreted via lactation. Contamination of drinking water can result in highly increased PFHxS serum levels due to the long elimination-time in humans.

116. In rodents, various effects on the liver have been observed from PFHxS exposure. Effect on liver lipid and lipoprotein metabolism and altered serum cholesterol, triglycerides and lipoproteins has been observed in both rodents and humans. Neurotoxic and neurodevelopmental effects have been observed in controlled laboratory experiments in mice and rats, and some studies indicate association between behavioral inhibition in children and certain PFASs (and PFHxS) exposure prenatally and in childhood. Effects on the thyroid hormone system have been reported cross-species (bird, rat, polar bear and human). Furthermore, several epidemiology studies indicate that the naïve and developing immune system might be vulnerable to certain PFASs and PFHxS exposure.

117. Certain PFASs, including PFHxS, contribute to the multiple-stressor effects observed in Arctic animals. Studies indicate that the level of certain PFASs in polar bear brain exceeded the threshold limit for neurochemical and hormonal alterations and can affect the thyroid homeostasis. Combined exposure of PFASs with other POPs have unknown consequences and may cause increased toxicity for heavily stressed species.

3.2 Summary of risk management evaluation information

118. Restricting or prohibiting PFHxS, its salts and PFHxS-related compounds would positively impact human health and the environment by decreasing emissions and subsequently human and environmental exposures.

119. PFHxS, its salts and PFHxS-related compounds are synthetic substances with no known natural occurrence. C₆, C₈ and C₁₀ perfluoroalkanesulfonic acids (PFASs) were mainly produced by 3M from 1958 in US and from 1971 in Belgium, up to 2002. Reported production of PFHxS by 3M in US from 1958 to 1997 was approximately 228 metric tons. After phaseout of production from 3M, production continued at one manufacturer in Italy that advertised PFHxS and its precursors until it filed bankruptcy in November 2018. However, main production and use has then moved to Asia and increased since 2002, with at least some manufactures in China. PFHxS is and has been unintentionally produced during the electrochemical fluorination (ECF) processes of producing other PFASs. POSF-based products may contain up to 10 % PFHxS as unintentional impurities if not removed to increase purity.

120. Use of PFHxS, its salts and PFHxS-related compounds are overlapping with use categories for PFOS-compounds, and in many applications PFHxS or PFHxS-related compound have been used as replacements for PFOS. Intentional use, in at least, the following applications: (1) AFFFs for firefighting; (2) metal plating; (3) textiles, leather and upholstery; (4) polishing agents and cleaning/washing agents; (5) coatings, impregnation/proofing (for protection from damp, fungus, etc.); and (6) within the manufacturing of electronics and semiconductors have been identified. In addition, other potential use categories may include pesticides, flame retardants, paper, and in the oil industry as well as cook wear. In addition, PFHxS, its salts and related compounds have been used in certain per- and polyfluoroalkyl substances (PFASs) based consumer products.

121. The ongoing assessment of alternatives to PFOS under the Stockholm Convention has revealed that alternatives are available for all potential applications of PFHxS. Alternatives include both fluorinated and non-fluorinated substances as well as alternative technical solutions. Information on availability, accessibility and price of alternatives, as well as information on regulatory measures and use in different countries, reveal that the socioeconomic costs of implementing a ban and/or restriction on the use of PFHxS are considered small and outweigh the benefits of an elimination/ regulation. High costs are estimated for remediation of contaminated "hot spots", such as old and current fire-fighting foam training sites and airports, landfills for industrial waste, and hazardous waste, as well as for the removal of PFASs, including PFHxS, from drinking water and water sources affected by PFHxS (and other PFASs) contamination.

122. Emissions of PFHxS to the environment occur at all its life cycle stages but are assumed to be highest during service life and in the waste phase. PFHxS is ubiquitous in environmental compartments such as surface water, deep-sea water, drinking water, waste-water treatment plants (WWTP) and leachates from landfills, sediment, groundwater, soil, the atmosphere, dust, as well as biota (including wildlife), and humans globally. Efficient control measures for the handling of waste will be essential to reduce environmental levels. According to Article 6 of the Convention, waste shall be disposed of in such a way that the POP content is destroyed or irreversibly transformed so that it does not exhibit the characteristics of POPs, or otherwise disposed of in an environmentally sound manner when

destruction or irreversible transformation does not represent the environmentally preferable option, or the POP content is low.

3.3 Suggested risk management measures

123. No critical uses have been identified and no exemptions have been requested hence the control measure “Prohibition or restriction of production, use, import and export” is best achieved under the Convention by listing PFHxS, its salts and PFHxS-related compounds in Annex A without exemptions.

4. Concluding statement

124. [The Committee recommends to list PFHxS, its salts and PFHxS-related compounds in Annex A without any exemptions.]

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